VEGETATION PATTERNS IN RELATION TO SLOPE POSITION IN THE CASTLE CLIFFS AREA OF SOUTHERN UTAH

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ABSTRACT.— Vegetation patterns in relation to slope position were studied on four foothill knolls in the Castle Cliffs area of Washington County, Utah. Study plots were established at four different slope positions: ridge top, upper slope, lower slope, and floodplain. Exposed rock was highest on the ridge top; exposed soil was highest on the floodplain; soil depth increased downslope. Plant life form varied with respect to slope position. Grass, annuals, and cryptogamic crust cover was highest on the ridge top and shrubs were most prominent on the midslope. Forb cover gradually increased downslope. Succulents were restricted to the ridge top or floodplain. Species distribution was distinct and strongly correlated to slope position. Two sets of congeneric species showed strong patterns of niche separation. The vegetation of the slopes is highly distinct at the ridge top and floodplain and grades toward the midslope from both ends.

Vegetation composition and its relationship to slope position has been of interest to researchers for many years. The majority of work reported has been conducted in areas with moderate climates and annual precipitation exceeding 15 inches. Foothill knolls in the Castle Cliffs area of southern Utah provide an opportunity to study such relationships in a more arid and extreme climate.

Moretti and Brotherson (1982) examined vegetation and soil factors in relation to slope position on foothill knolls in the Uintah Basin of Utah. They reported that differences in plant life-form composition, plant cover, and wind-adapted growth forms were significant between the top and bottom of the slopes. Plant diversity was also found to vary with slope position.

In a study of vegetation on windswept ridges in south central Wyoming, Anderson et al. (1976) found that mat-forming plants were more predominant on areas subjected to strong winds. Less windy areas were occupied by sagebrush-grass communities.

In the montane steppes of central Utah, England (1979) also found vegetation patterns varied with slope position. Both life form and species composition changed from the ridge top to the base of the slope, with grasses dominating the base of the slope and shrubs dominating the ridge top. Plant moisture stress was also found to vary with slope position.

Moisture relationships associated with slope position also provide an opportunity to detect correlations between ecological variations in the habitat and plant morphology. Anderson's (1977) studies of several cactus groups suggested that the surface area to volume ratio (S/V) of various species of cacti can be correlated to moisture and temperature stress associated with climatic conditions in the area they inhabit. He indicates that the S/V ratio would be expected to increase as moisture and temperature stress decrease. Microclimates (soil and moisture differences) associated with topographical differences with respect to desert knolls may therefore be similarly linked with differences in morphology among species of cacti.

The objective of this study was to determine differences in vegetative patterns with respect to slope position in a desert ecosystem and to identify possible correlations of slope position to variations in life form, cactus morphology, and species niche specialization.

STUDY SITE

The study site is located 16 km north of the Utah-Arizona state line along Highway 91 in Castle Cliffs Wash (Fig. 1). The area lies in a transition zone between the hot Mohave desert and the cold Great Basin desert. Soils are shallow and well drained and have from 0% to 10% slopes. Parent materials are mixed

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Fig. 1. Map of study site location in Castle Cliffs Wash area of Washington County, Utah.

limestone, gneiss, schist, sandstone, and basalt (Bowns 1973). Altitude of the study area is about 1420 m. The average annual precipitation in the area is 29.6 cm (Hodges and Riechelderfer 1962). Annual temperatures range from 47 C to −23 C (Eubank and Brough 1979).

Materials and Methods

Four slopes of southwest exposure near Castle Cliffs Wash were selected for study. Elevation differences from top to bottom of the slope varied from 30 to 50 m. Slope steepness varied between 16% and 20%. Each slope was sampled with four 10 × 10 m (0.01 ha) study plots. The plots were established at four different slope positions; ridge top, upper slope, lower slope, and floodplain. Each plot was randomly subsampled with 10-quarter-meter-square quadrats. Vascular plant cover was estimated for each species (Daubenmire 1959) at each quadrat. In addition, cover contributed by rock, litter, and cryptogamic crusts was estimated. Soil depth was measured with a penetrometer within five of the 10-quarter-meter-square quadrats (Greenwood and Brotherson 1978). Total living plant cover, plant cover by life form (i.e., trees, shrubs, perennial forbs, perennial grasses, annuals, cryptogams, succulents) were ocularly estimated from each quadrat following a procedure suggested by Ostler (1980).

Cluster analysis techniques (Sneath and Sokal 1973) were applied to similarity index values (in percent) computed via the formula: $SI = \Sigma\min(XiYi) / \Sigma\max(XiYi)$ where SI is the similarity index between two study sites: the $\Sigma\min(XiYi)$ represents the sum of the minimum values from the paired relative abundance figures across all species found in stands (XY), and the $\Sigma\max(XiYi)$ represents a similar figure for the maximum values of the same two stands (Ruzicka 1958). Clustering the above indices employed unweighted pair/group clustering procedures (Sneath and Sokal 1973). This method computes the average similarity of each unit to the cluster, using arithmetic averages. It is widely used and has been found to introduce less distortion than other methods (Kaesler and Cairns 1972). Using this technique we expected to cluster those study plots that were most alike together and thus aid in uncovering relationships existent between them.

Means were calculated for all biotic and abiotic data. In addition, niche breadth and overlap indicies (Colwell and Futuyma 1971) were computed for all species found in the study area. Species were clustered from niche overlap values. Plant nomenclature follows Welsh and Moore (1973) for the dicotyledons and Cronquist et al. (1977) for the monocotyledons.

In an attempt to compute surface area to volume ratios for each cactus species encountered, individual plants in each plot were measured. Barrel cactus (*Ferocactus acanthoides*) was measured for height and width; numbers of flutes on each plant were recorded, and average depth of the flutes was determined. Measurements of buckhorn cholla (*Opuntia acanthoecarpa*) included the length and width of the individual segments on the plant and the total number of segments for each plant.

Results and Discussion

As shown in Table 1, soil depth was greatest at the base of the slope and decreased with

TABLE 1. Mean values for the environmental factors (biotic and abiotic) for the slopes of the Castle Cliffs area of southern Utah.

Environmental factors	Slope position			
	Ridge top	Upper slope	Lower slope	Floodplain
ABIOTIC FACTORS				
Soil depth (dm)	0.8	2.1	4.1	5.8
Rock cover (%)	70.4	7.3	10.6	13.6
Bare ground (%)	7.8	56.5	38.2	60.3
SSMI	1.3	2.0	2.7	3.3
Litter cover (%)	8.2	5.1	8.3	8.1
BIOTIC FACTORS				
Average vegetation height (dm)	4.9	5.9	5.2	5.0
Total living cover (%)	28.9	34.8	39.6	29.7
Tree cover (%)	4.2	0.0	0.0	0.5
Shrub cover (%)	14.8	27.5	39.5	15.9
Forb cover (%)	1.4	2.0	2.2	3.8
Grass cover (%)	5.8	1.8	3.5	3.4
Annual cover (%)	5.7	3.3	3.1	3.4
Cryptogam crust cover (%)	5.1	3.2	0.9	0.1
Succulent cover (%)	3.7	0.0	0.0	4.4
Yucca species cover (%)	0.1	2.8	0.4	11.2

TABLE 2. Mean cover (%) of plant species in relation to position in the Castle Cliffs area of southern Utah.

Species	Slope position			
	Ridge top	Upper slope	Lower slope	Floodplain
Cersium species	0.3			
Coleogyne ramosissima	12.8	70.5	15.6	1.2
Cowania mexicana	1.7		0.9	0.4
Dalea fremontii	0.4			
Ephedra nevadensis	9.1	8.7	8.9	16.5
Eriogonum microthecum	3.0	0.3		3.6
Ferocactus acanthodes	12.9			
Gutierrezia microcephala	2.5	1.8	65.6	11.6
Gutierrezia sarothrae	47.3	0.3	1.7	
Hymenochlea salsola			1.0	
Juniperus osteosperma	0.3			
Lithospermum multiflorum	3.0			0.9
Opuntia acanthocarpa			4.5	9.6
Opuntia polyacantha		0.8		2.1
Prunus fasciculata			0.4	
Senecio longilobus			4.5	20.1
Yucca baccata	0.5	17.5	1.2	
Yucca brevifolia	2.3	0.3	0.5	11.6

elevation, reaching a minimum at the ridge top. This is probably the result of soil movement downslope by water, wind, and gravity. Exposed rock was highest on the ridge top. Rock outcroppings on the tops of knolls are a prominent feature of the area and reflect the high values of exposed rock. Habitat conditions on the slopes of the knolls (i.e., exposed rock, varying soil depths, exposure to wind, etc.) create a moisture gradient downslope (England 1979). Ridge tops are characterized as being the most zeric, with moisture stress decreasing downslope. Therefore, the most mesic conditions exist at the slope base. Total vegetation cover and litter cover were sparse over the entire area and may therefore have little significant effect on water runoff or soil stabilization on the slopes.

Plant life forms showed significant variation in relation to slope position (Table 2). Cover of cryptogamic crusts was highest on the ridge top and steadily decreased downslope. In midslope areas the velocity of water movement over the ground may prevent establishment of cryptogams. The near absence of cryptogams at the base of the slope may be

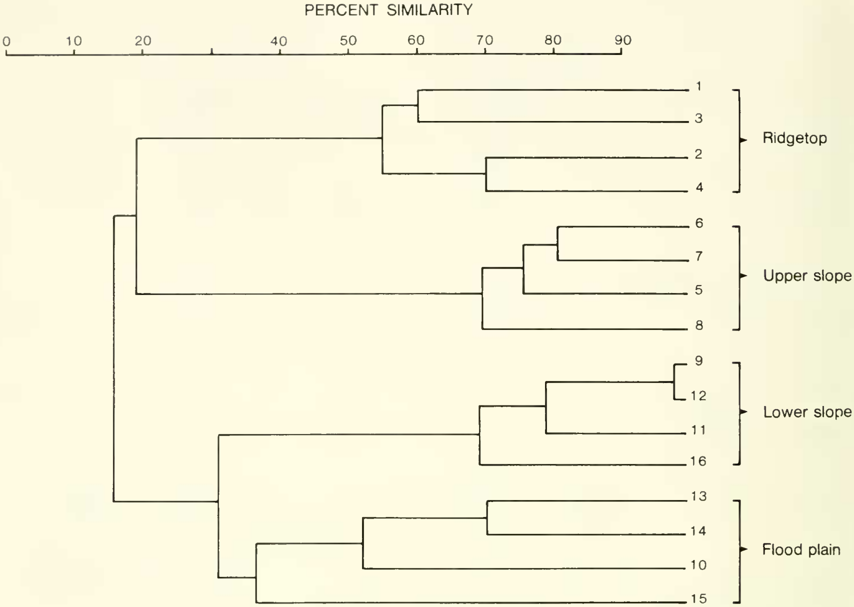

Fig. 2. Cluster analysis dendrogram of 16 study sites with respect to slope position. Clustering based on similarity of vegetative cover.

due to flooding and soil movement that occur during thunderstorms in the area. Shrub cover was highest in the midslope positions, decreasing upslope and downslope. Forb cover generally increased downslope, and perennial grasses and annuals were most prominent at the ridge tops but were found at all slope positions. Succulents (Cacti) were restricted to the ridge top and floodplain sites. This may be due to competition from the elevated levels of shrub cover at the midslope positions (Table 1). Yucca cover was most predominant on the floodplain sites.

Cluster analysis was used to group the study sites on the basis of similarity in vegetative cover (Fig. 2). As shown, four groups emerged. With the exception of two sites (10 and 16), the clustering correlated well with slope position. Patterns were strong, with most stands clustering above the 55% level. The floodplain group clustered more loosely (at the 32% level), indicating greater variability in the vegetation of those sites.

The high level of clustering in the groups suggests a causal effect for the occurrence of dominant species that characterize each slope position (Table 2). The ridge top and upper slope sites appear to be more similar to each other vegetatively than they are to the lower slope and floodplain sites. The reverse is also true. The vegetation on the slopes can be described as being highly distinct at the ends of the slope gradient (i.e., ridge top and floodplain) and grading toward the midslope from both ends.

A list of important plant species was developed for each slope position (Table 2). Threadleaf snakeweed (*Gutierrezia microcephcela*), blackbrush (*Coleogyne ramosissima*), Nevada ephedra (*Ephedra nevadensis*), and Joshua tree (*Yucca brevifolia*) were found at all slope positions and therefore are apparently adapted to tolerate a wide range of environmental conditions. However, differences in cover values at the four slope positions indicate that each species has optimum

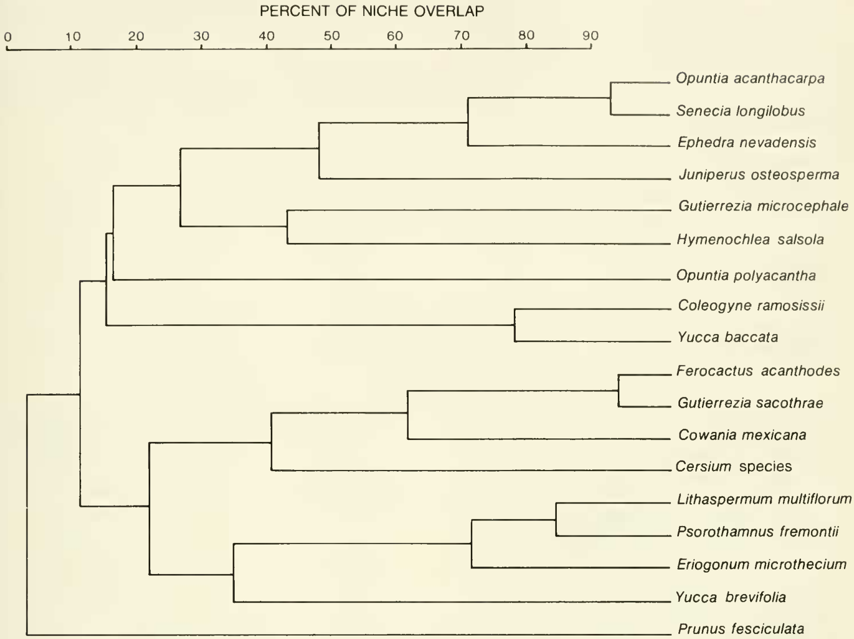

Fig. 3. Cluster analysis dendrogram of species. Clustering based on niche overlap values.

growing conditions at only one position along the slope. Seventy percent of the blackbrush cover is at the upper-slope position, 96% of threadleaf snakeweed's cover occurred at the lower-slope position, and 79% of Joshua tree's cover and 38% of Nevada ephedra's cover occurred in the floodplain. Cover values for other species also showed restricted distribution patterns. Thistle (*Cersium* sp.), cliffrose (*Cowania mexicana*), Fremont Dalia (*Dalea fremontii*), and barrel cactus (*Ferocactus acanthodes*) had significantly higher cover values on the ridge top; Datil yucca (*Yucca baccata*) was higher at the upper slope. Nevada ephedra (*Ephedra nevadensis*), slenderbush eriogonum (*Eriogonum microthecum*), threadleaf groundsel (*Senecio longilobus*), prickly pear (*Opuntia polyacantha*), buckhorn cholla (*Opuntia acanthocarpa*), and Utah juniper (*Juniperus osteosperma*) are highest on the floodplain.

To help clarify relationships between these patterns of distribution, the species were clustered on the basis of niche overlap values (Fig. 3). As shown, there are four distinct cluster groups. The groups generally reflect distribution patterns of species that correlate with slope position. For example, blackbrush and Datil yucca are species restricted to the upper midslope sites. Broom snakeweed and barrel cactus are the most closely associated species. Both occurred predominantly on the ridge top and therefore appear best adapted to the more xeric areas of the study site. A strong association also exists between the distribution patterns of the blackbrush and Datil yucca. Optimum growing conditions for these species seem to be present on the upper slopes of the arroyos. The cluster containing buckhorn cholla, threadleaf groundsel, Nevada ephedra, and Utah juniper also suggests similar habitat preferences. These species occurred mainly on the floodplain in the study area. Joshua tree showed no strong associations with any other species on the site. This is probably due to its occurrence at all slope positions with only a slight preference for the floodplain. Other associations in the cluster

TABLE 3. Correlation coefficients of biotic and abiotic factors with respect to each other and to slope position. Correlation coefficients of above .468 are significant at the 0.05 level, above .588 are significant at the .01 level, and above .708 are significant above the .001 level.

Factor	Bare ground	Soil depth	Rock	Litter
Gutierrezia sarothrae	−.777	.545	.879	
Ferocactus acanthoides	−.766	.565	.881	
Opuntia acanthocarpa		.786		
Senecio longilobus		.599		
Coleogyne ramosissima				−.576
Yucca baccata				−.632
Grasses	−.645		.750	
Forbs		.804		
Annuals	−.617		.686	
Cryptogams		−.546	.514	
Soil depth	.537			
Rock	−.818			
Total living cover			−.653	

are due to the relatively low cover contributed by each species.

The plant life forms, species cover values, and environmental factors were subjected to correlation analyses (Table 3), from which several significant correlations developed. Most of the correlations appear related to slope effect. For example, grasses as a life form are negatively correlated with bare ground and positively correlated with rock. Since ridge tops had large areas of exposed rock, the floodplain had large areas of bare ground, and grasses were predominant on the ridge tops and less important downslope, the implied relationships appear valid. The same holds true for cryptogamic crusts that were negatively correlated with soil depth and positively correlated with rock. All factors examined seem to exhibit patterns with respect to slope.

Disjunct distribution patterns of two sets of congeneric species, (1) Datil yucca and Joshua tree and (2) Broom snakeweed and threadleaf snakeweed, are conspicuous. All four species are known to be widely distributed in the Mojave desert, but Broom snakeweed and Datil yucca extend further north into the Great Basin desert. On the study sites Datil yucca and broom snakeweed were primarily restricted to the ridge tops and upper slopes, and Joshua tree and threadleaf snakeweed were most predominant on the floodplain and lower slopes.

Since the study site lies in a transition zone between the Great Basin desert on the north and the Mojave Desert on the south, differences in the habitat requirements of these congeneric species are more easily recognized. The effects of slope on the overall environmental complex allows for the geographical separation of species in localized areas while having in common distribution patterns across large geographical areas.

Also, the disjunct distribution patterns of barrel cactus and buckhorn cholla (both of the Cactaceae) provide us opportunity to examine variations in plant morphology that may be related to habitat differences. Anderson (1977) suggests that surface area to volume ratios of various cactus species may be correlated with differential temperature and moisture conditions of their habitats. According to his theory, the surface area to volume ratios would be expected to increase as moisture and temperature stress decrease. Although our data were inconclusive because of difficulties we experienced in measuring surface area and volume in these cacti, the cacti exhibit very different morphologies. The buckhorn cholla that occupies the most mesic part of the study site is tall and highly branched. Barrel cactus, on the other hand, is short and unbranched and occupies the most xeric parts of the study area. If the morphological differences in these two species is related to environmental stress and/or other habitat differences, the causal relationships are not readily apparent. Further work is presently underway to investigate this phenomena.

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